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POST CYCLE TEMPERATURE CONDITIONING FOR THE M795 155-mm PROJECTILE

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13. ABSTRACT
An engineering study was performed to define the post cycle conditioning process parameters for the M795 155-mm HE projectiles. The study consisted of two phases: determination of TNT cast growth characteristics under post cyclic conditions based on the use of TNT pellets and the determination of the heat transfer profiles of a TNT cast loaded M795 projectile. The tests determine the effects of cycle temperature and time on resultant cast growth. Based on the results an optimized post cyclic conditioning process for the M795 was established.

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BACKGROUND

Post cycle conditioning tests were conducted from February 1997 through May 1997 to determine the optimum parameters for the M795 155-mm projectile.

The temperature cycling of cast TNT results in the irreversible growth of the cast explosive. This phenomena has been used to increase cast tightness and minimize base separation and porosity in large caliber projectiles loaded with TNT based explosive compositions.

TNT is typically loaded into large caliber munitions by casting of the molten explosive. TNT shrinks approximately 12% upon solidification. This shrinkage can result in cavities within the cast as well as separation between the explosive cast and the interior surface of the projectile cavity. The presence of cavities or base separation in high explosive (HE) projectiles will result in the heating of the encapsulated air due to adiabatic compression during projectile setback. Depending on the particular conditions premature ignition of the explosive may result. Therefore, the amount of allowable base separation and cavitation within HE shells is strictly controlled. The limit for base separation within artillery projectiles has been set at 0.015 in.

Since base separation is of critical importance for large caliber artillery projectiles post cycle conditioning is used to ensure that a tight explosive cast with minimal base separation is produced. The TNT cast of the M795 155-mm HE projectile has a 25-in. high explosive column (approximately 60% longer than the M549). This geometry makes the projectile particularly susceptible to developing base separation (due to cast shrinkage during solidification). Additionally, the M795 is more vulnerable to adiabatic compression ignition due to high hydrostatic pressures generated in the projectile base during setback.

PROGRAM OBJECTIVES

The objective of this study was to define post cycle conditioning process parameters for the M795 155-mm HE projectile that will provide a high degree of explosive cast growth thereby minimizing/eliminating any potential base separation/cavities introduced during the solidification of the TNT cast.

PROGRAM PLAN

The program was structured in two phases:

1. Determination of TNT cast growth characteristics under post cyclic conditions based on the use of TNT pellets

2. Determination of the heat transfer profiles under post cyclic conditions of a TNT cast loaded M795 projectile

TNT PELLET GROWTH TESTS

TNT Pellet Growth - Procedure

Explosive cast growth testing was performed using TNT pellets to determine the irreversible growth that resulted from varying the parameters of the conditioning cycles. Table 1 specifies the parameters for pellet growth tests.

Table 1
Pellet test matrix

Test No.	Cycles	Cycle			
		Upper Temp (°F)	Time (hrs)	Lower Temp (°F)	Time (hrs)
1	3	140	12	70	12
2	4	140	6	70	6
3	4	150	6	70	6
4	4	145	6	65	6
5	4	135	6	70	6
6	4	130	6	70	6
7	2	120	6	70	6

The TNT pellets used in the tests were cast at a nominal 1.75-in. diameter and cut to 6-in. lengths. The relative changes in pellet size were measured with calipers following each cycle. The pellets were marked radially and axially to assure that the measurements were taken in the same location each time. The pellets were at approximately 70°F each time that measurements were taken. The pellets were measured following each 12-hr cycle, or after every other 6-hr cycle. Each test consisted of a minimum of four pellets. The pellets were cycled in an unconfined configuration (fig. 1).

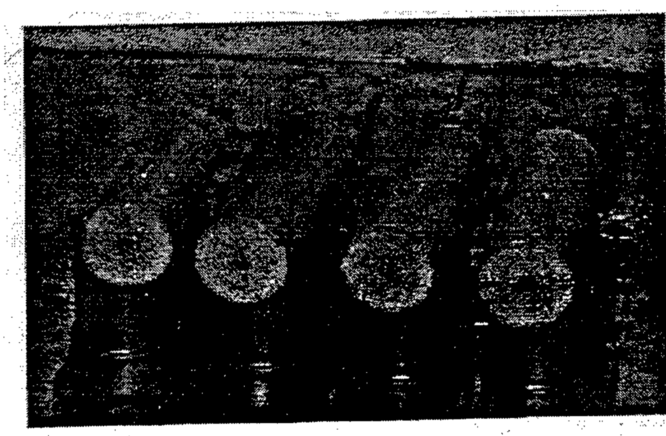


Figure 1
TNT pellets

Each cycle consisted of raising the temperature in the chamber and dwelling at that temperature for a set period of time followed by a temperature reduction and dwelling for a set period of time. Figure 2 illustrates a typical two-cycle pellet temperature profile.

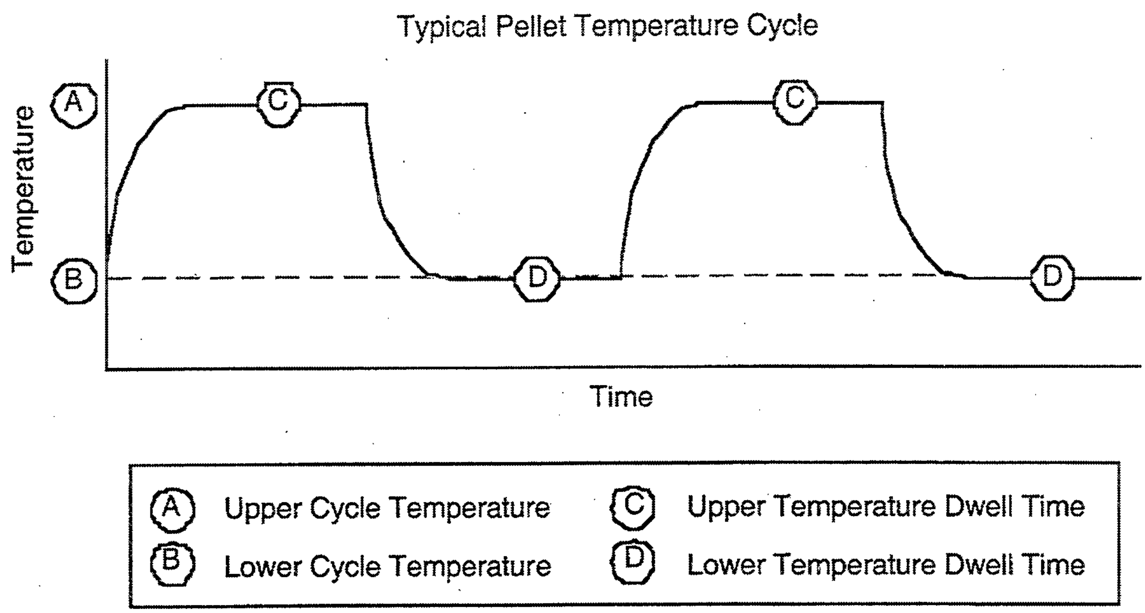


Figure 2
Typical pellet temperature cycles

The conditioning chamber, which was used for the pellet tests, is shown in figure 3. The temperature within the chamber was controlled via a programmable controller.

Testing of an instrumented pellet showed that the core of the pellet reached the chamber temperature in approximately 1 hr.

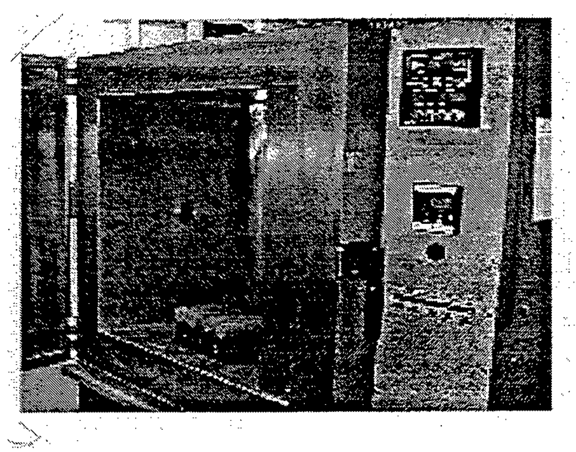


Figure 3
Conditioning chamber

TNT Pellet Growth - Results

The results of the tests have identified that both cycle temperature and dwell time have a significant impact on pellet growth. The standard deviations of the measured pellet growth between pellets within each test ranged between 5 and 10%, indicating good reproducibility. The data indicated that cast growth in both the longitudinal and radial directions were approximately equal.

Figure 4 shows the relative growth of length versus diameter for a standard 140°F/70°F cycle with 12 hr dwell times at each temperature.

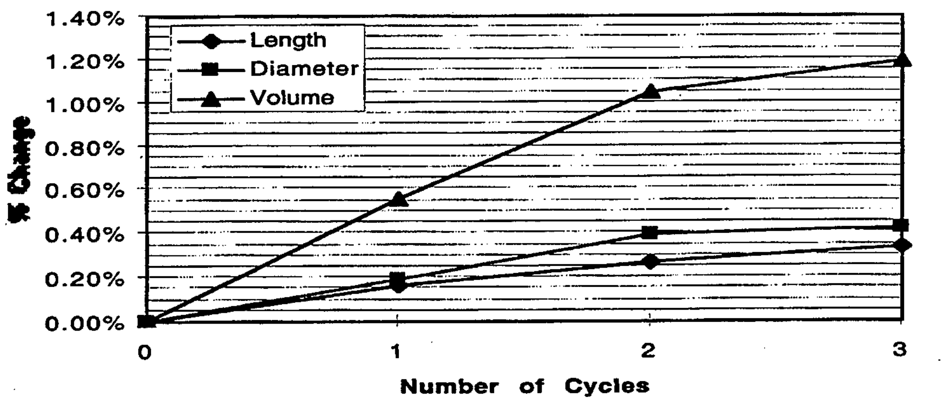
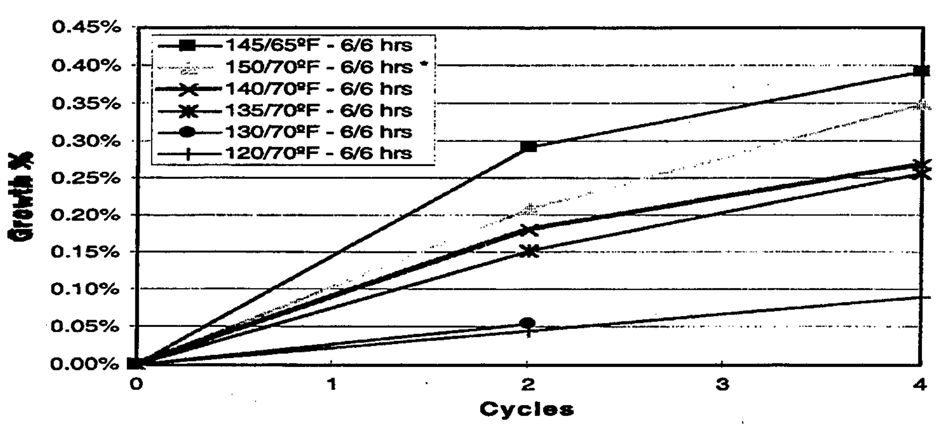


Figure 4
TNT pellet growth (140°F/70°F – 12/12 hrs dwell time)

Figure 5 shows the effect of upper cycle temperature on pellet growth. The data shows that cast growth is substantially effected by varying the upper cycle temperature between 130°F and 150°F. In addition, it shows that an upper cycle temperature of 140°F results in 350% more growth than the growth produced from an upper cycle temperature of 130°F. Additionally, the data shows that two 140°F/70°F cycles will result in ≈ 0.17% growth compared to 0.05% growth for two 130°F/ 70°F cycles. Two 150°F/70°F cycles should yield ≈ 0.25 - 0.30% growth.



Note: During the first cycle of the 150°F/70°F trial an unplanned temperature drop was experienced. When a correction factor is applied to the 150°F/70°F data, a growth profile equal to or exceeding the 145°F/65°F cycle results.

Figure 5
TNT pellet growth (temperature versus time) for 6-hr cycles

Figure 6 illustrates the effect that differing dwell times have on pellet growth. The graph compares the difference between a 6-hr and 12-hr dwell time on a 140°F/70°F cycle. The graph shows that 0.27% growth for the 12-hr cycle vs. 0.17% for the 6-hr cycle.

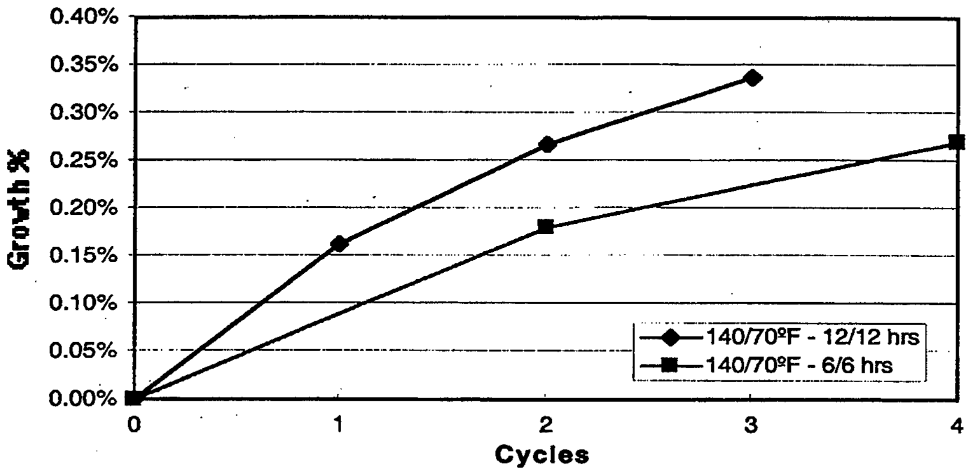


Figure 6
TNT pellet growth 140°F/70°F cycles (6-hr versus 12-hr dwell times)

Figure 7 illustrates that additional cycles will result in continued pellet growth. The data showed that during the prescribed tests, pellet growth approaching 3% of the total volume was achieved.

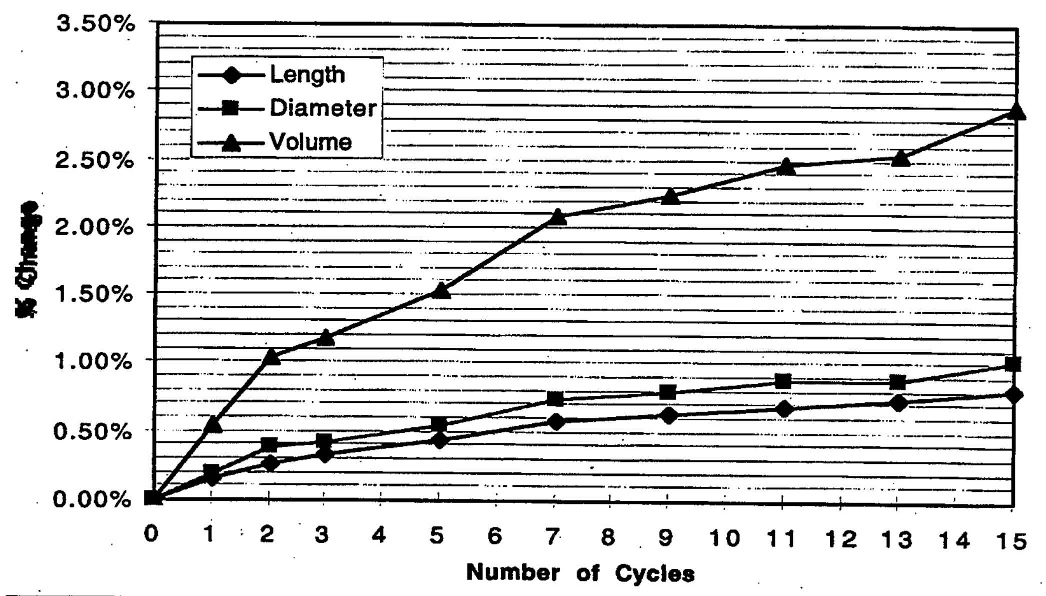


Figure 7
Multiple cycle TNT pellet growth

M795 THERMAL PROFILES

Because of the low thermal conductivity of TNT coupled with the thick steel casing of the M795 projectile, it was necessary to determine the actual time required for the explosive at the center of the cast to reach the objective cycle temperature.

Thermal Profile - Procedure

The time-temperature profile of the M795 based on known external conditions was determined using the following procedure:

Two M795 projectiles were each instrumented with four J-type thermal couples positioned to register temperatures along the central axis of the explosive cast as well as two external thermal couples registering the metal part temperatures (fig. 8). The projectiles were placed within a temperature conditioning chamber (Picatinny Arsenal B3109). During each heating or cooling cycle, six temperatures were measured from each projectile as well as the air temperature within the chamber.

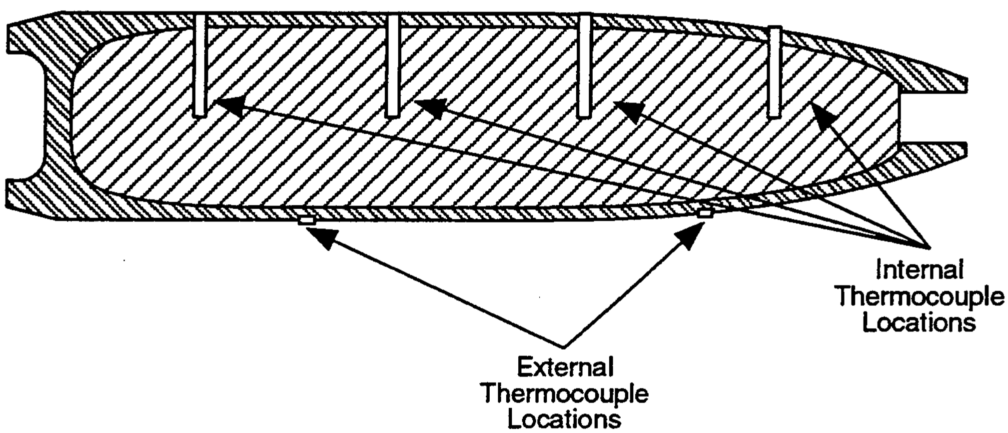


Figure 8
M795 instrumented projectile (thermocouple locations)

Thermal Profile - Results

The data showed that the temperature of thermal couple 3 (lower middle of the cast) was the slowest to respond to the external temperature changes. Figure 9 shows a typical M795 projectile temperature-time profile. The graph illustrates how the explosive core temperature can trail the metal parts surface temperature by as much as 4.5 hrs. The data showed that after 9 hrs the explosive core temperature was 10°F less than the chamber and that after 12 hrs the explosive core temperature was 5°F less than the chamber air temp. This data was used to establish the proper ramp-up times in the post cycle procedure.

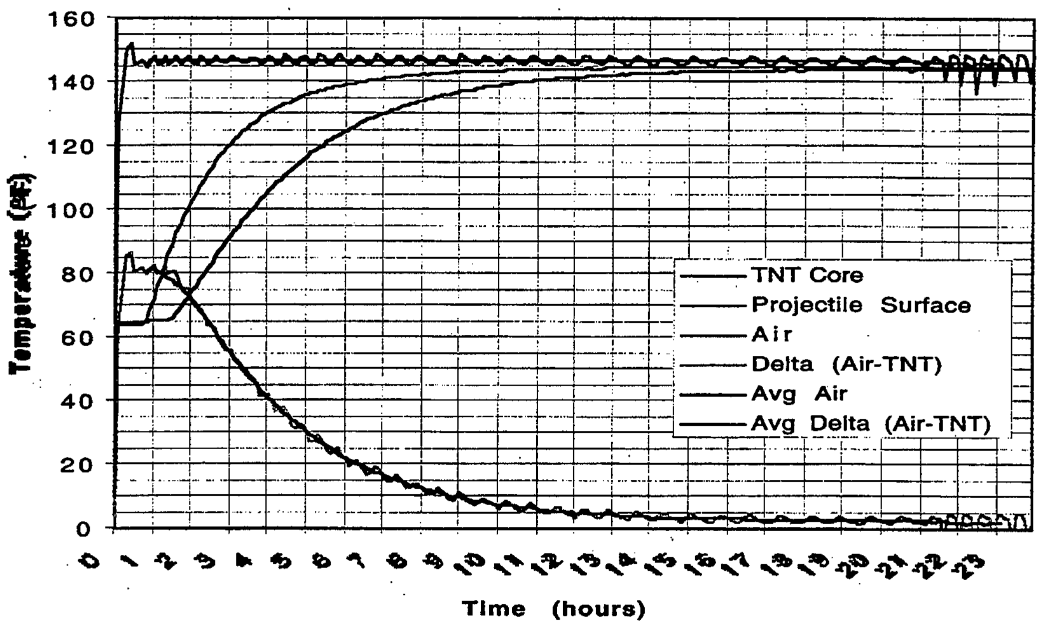


Figure 9
M795 temperature-time profile

CONCLUSIONS

The data from these two test programs were integrated in order to develop the current M795 post cycle conditioning process for implementation at Iowa Army Ammunition Plant (IAAP). The process is controlled based on the exit air temperature. The detailed process is specified in appendix A.

The selected procedure was chosen to insure that the explosive cast receives at a minimum two cycles of 135°F for 6 hrs and 70°F for 6 hrs. A series of two 135°F/70°F (6 hrs) cycles will yield an increase in cast length of approximately 0.15%. This equates to an increase of approximately 0.038-in. in length of an M795 explosive cast. Based on a review of M796 test data, it was determined that this would provide sufficient growth to eliminate any base separation, which formed as a result of TNT shrinkage during solidification. It has been found that in typical operation at IAAP using the specified procedure, that a temperature of 140°F (hot) and 70°F (cold) is actually maintained for a 12-hr dwell time. This results in cast length growth of approximately 0.27% for a two cycle series.

As of March 1998, over 14,000 M795 projectiles have been loaded at IAAP and subjected to the specified post cycle conditioning procedure. From each post cycle lot the projectiles that showed the worst base separation (from X-ray) were subjected to a 200G nose drop and sectioned to directly measure base separation. All projectiles sectioned to date have shown zero base separation.

APPENDIX A
POST CYCLIC CONDITIONING PROCESS

A. Place the loaded projectile(s) in a heating/cooling chamber.

B. Circulate heated air [68°C (155°F) maximum] around the projectiles. After the temperature of the air exiting the chamber reaches 60°C (140°F), continue to circulate heated air through the chamber to maintain exit air temperature between 60°C (140°F) and 65°C (150°F) for a minimum of 18 hrs.

C. Circulate cool air [13°C (55°F) minimum] around the projectiles. After the temperature of the air exiting the chamber is reduced to 21°C (70°F), continue to circulate cool air through the chamber to maintain exit air temperature between 21°C (70°F) and 16°C (60°F) for a minimum of 18 hrs.

D. Circulate heated air [68°C (155°F) maximum] around the projectiles. After the temperature of the air exiting the chamber reaches 60°C (140°F), continue to circulate heated air through the chamber to maintain exit air temperature between 60°C (140°F) and 65°C (150°F) for a minimum of 18 hrs.

E. Circulate cool air [13°C (55°F) minimum] around the projectiles. After the temperature of the air exiting the chamber is reduced to 24°C (75°F), continue to circulate cool air through the chamber to maintain exit air temperature between 24°C (75°F) and 16°C (60°F) for a minimum of 12 hrs.

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